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[TITLE OF THE INVENTION] Semiconductor Device

[ABSTRACT]

[SUBJECT] A semiconductor device capable of reducing power loss during a low-output operation, and of also adopting itself to the high-output operation is provided.

[SOLVING MEANS] The semiconductor device comprises a power MOSFET 2 which turns on upon being applied with a first drive voltage to the gate electrode thereof, and an IGBT which turns on upon being applied with a second drive voltage having a level different from that of the first drive voltage to the gate electrode thereof, wherein the first voltage-driven switching element and the second voltage-driven switching element are connected in parallel with respect to current to be supplied to a load, and is configured so that the first drive voltage for driving the power MOSFET only is applied to the gate electrode when a small current is supplied to a load, and that the second drive voltage, which is larger than the first drive voltage and is for mainly driving the IGBT, is applied to the gate electrode when a large current is supplied to the load.

[CLAIMS]

[Claim 1] A semiconductor device comprising a first voltage-driven switching element which turns on upon being applied with a first drive voltage to the drive electrode thereof, and a second voltage-driven switching element which

turns on upon being applied with a second drive voltage having a level different from that of the first drive voltage to the drive electrode thereof,

wherein said first voltage-driven switching element and said second voltage-driven switching element being connected in parallel with respect to current to be supplied to a load.

[Claim 2] The semiconductor device as claimed in Claim 1, having a totem pole configuration in which one pair of said first and second voltage-driven switching elements connected in parallel, and another pair of said first and second voltage-driven switching elements connected in parallel, are connected in series.

[Claim 3] The semiconductor device as claimed in Claim 1 or 2, further comprising:

a current detection section for detecting current flowing in said load; and

a control section for switching a voltage to be output to the drive electrodes of said first and second voltage-driven switching elements, connected in parallel, between said first drive voltage and said second drive voltage based on a current value detected by said current detection section.

[Claim 4] The semiconductor device as claimed in Claim 3, wherein said control section outputs said first drive voltage having a level lower than that of said second drive voltage when said current value detected by said current detection section is smaller than a predetermined value.

[Claim 5] The semiconductor device as claimed in Claim 4, wherein a first threshold voltage of said first voltage-driven

switching element and said second threshold voltage of said second voltage-driven switching element differs by 2 V or more, and said predetermined value is set to V_d/R_{on}, where V_d represents conduction resistance of said first voltage-driven switching element, and V_d represents voltage drop under current supply of said second voltage-driven switching element.

[Claim 6] The semiconductor device as claimed in Claim 3, further comprising a first resistive element and a second resistive element; said first resistive element having a terminal connected to the drive electrode of said first voltage-driven switching element, said second resistive element having a terminal connected to the drive electrode of said second voltage-driven switching element, said first and second resistive elements having the other terminals connected to a common electrode; and wherein

said control section outputs said first drive voltage or said second drive voltage to said common electrode.

[Claim 7] The semiconductor device as claimed in Claim 3, further comprising a third resistive element having a terminal connected to the drive electrode of said first voltage-driven switching element and the other terminal connected to the drive electrode of said second voltage-driven switching element;

a fourth resistive element having a terminal connected to the drive electrode of said first voltage-driven switching element; and

a third switching element connected to the other terminal of said fourth resistive element, and turns said first voltage-driven switching element off based on a control signal from

said control section while being mediated by said fourth resistive element; wherein

said control section outputs said first drive voltage or said second voltage to one terminal of said third resistive element.

[Claim 8] The semiconductor device as claimed in any one of Claims 1 to 7, wherein said first voltage-driven switching element is a metal-oxide-semiconductor field effect transistor, and said second voltage-driven switching element is an insulated gate bipolar transistor.

[Claim 9] A power control instrument using the semiconductor device as claimed in any one of Claims 1 to 8.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a semiconductor device, and in particular to a technique of controlling, using voltage-driven switching elements, electric power to be supplied to a load, and is typically applicable to power control instruments such as air conditioners.

[0002]

[Background Art]

Voltage-driven semiconductor element is widely used as a switching element in a variety of fields by virtue of its advantages of an extremely small power loss under driving and a desirable controllability as compared with those of generally-adopted current-driven semiconductor devices such as bipolar transistor. In particular in the fields where high voltage and

large power are handled, these advantages add the value. Examples of representative voltage-driven semiconductor element which fulfill the requirements include power MOSFET (metal-oxide-semiconductor field effect transistor) and IGBT (insulated gate bipolar transistor).

[0003]

As for the MOSFET, it is necessary to make the drain region thereof thicker, and to make the impurity concentration lower in order to adapt it to high-voltage use. Setting of this process conditions, however, undesirably raises resistance of the drain region, consequently raises the ON resistance, and thereby extremely increases power loss of the element *per se*.

[0004]

On the other hand, the IGBT is configured so as to connect the carrier injection layer to the drain of the power MOSFET, and is advantageous in that the ON resistance can be reduced to as small as approximately 1/4 of that of the power MOSFET, because the electric conductivity is modulated while being injected with carriers (holes, for example) from the carrier injection layer when the IGBT is turned on.

[0005]

Fig. 7 is a circuit diagram of an essential portion of an inverter circuit for driving motor, in which the IGBT is used as a switching element.

[0006]

The inverter circuit shown in Fig. 7 comprises a switching section 7a for supplying an adjusted power to a load, and a control section 7b for controlling operations of the switching

section 7a. The switching section 7a comprises three totem-pole-connection structures individually comprising IGBTs 7a-1 and 7a-2; IGBTs 7a-3 and 7a-4; and IGBTs 7a-5 and 7a-6. The IGBTs 7a-1 and 7a-2; IGBTs 7a-3 and 7a-4; and IGBTs 7a-5 and 7a-6 repetitively interrupt and allow current to be supplied to a three-phase motor 71 as the load in response to gate voltages VG1 and VG2; VG3 and VG4; and VG5 and VG6 respectively output from three control integrated circuits 7b-1, 7b-2 and 7b-3 of the control section 7b.

[0007]

In this circuit, a high source voltage V_p and a low source voltage V_n are applied from an external power source to two power source terminals, where the high source voltage V_p is supplied to the IGBTs 7a-1, 7a-3 and 7a-5, which are the switching elements on one side of the totem pole connection structure, and the low source voltage V_n is supplied via a resistor 72 for detecting current flowing in the three-phase motor to the IGBTs 7a-2, 7a-4 and 7a-6, which are the switching elements on the other side of the totem pole connection structure. The current flowing in the current detecting resistor 72 is detected as a voltage through sensing voltage terminals V_s of the control integrated circuits 7b-1, 7b-2 and 7b-3, and the gate voltages VG1 to VG6 are controlled corresponding to the sensed voltage.

[0008]

Upon being applied with the gate voltages VG1 and VG2; VG3 and VG4; and VG5 and VG6; power to be supplied from the output terminals of the IGBTs 7a-1 and 7a-2; IGBTs 7a-3 and 7a-4; and

IGBTs 7a-5 and 7a-6, respectively, to the W phase, V phase and U phase of the three-phase motor is controlled.

[0009]

Recent demands arisen for this type of large-power inverter circuit include energy saving, larger output based on an improved power factor, and conformity to the regulation on harmonic wave from power sources. Power control for solving these subjects adopts PAM (pulse amplitude modulation) control, in which the direct current is reduced in the low-output period, and raised in the high-output period. This is successful in realizing increase in the PWM duty ratio of the inverter, reduction in core loss in a high frequency region of the motor and reduction in loss of the switching elements, and energy saving. In particular as a high-output switching element applied to air conditioner or the like, it is general, as shown in Fig. 7, to use the IGBT which is a voltage-driven semiconductor element causative of only a small power loss under large current operation.

[0010]

In the inverter circuit shown in Fig. 7, the IGBT which is causative of only a small power loss under high output operation is advantageous because an air conditioner always operates under a high output condition at the start-up time irrespective of cooling and heating, but the output is halved in the stationary operation period succeeding to the start-up, which is the longest period for the air conditioner to operate under room temperature kept at constant after a set value is reached.

[0011]

Voltage drop ascribable to the junction, which amounts approximately 0.6 V to 0.8 V, however, always resides in the IGBT, and this makes it difficult to reduce the loss of the switching element *per se* under small-power operation, which is a stationary operation state, and this consequently limits the power loss of the instrument as a whole.

[0012]

The present invention is conceived after considering the above-described problems, and an object thereof is to provide a semiconductor device capable of reducing the power loss during a small-power driving of the load and of being adapted also to a large-power driving, and to provide a power control instrument using the same.

[0013]

[Means for Solving the Subjects]

To accomplish the aforementioned object, a semiconductor device according to the present invention comprises a first voltage-driven switching element which turns on upon being applied with a first drive voltage to the drive electrode thereof, and a second voltage-driven switching element which turns on upon being applied with a second drive voltage having a level different from that of the first drive voltage to the drive electrode thereof, wherein the first voltage-driven switching element and the second voltage-driven switching element are connected in parallel with respect to current to be supplied to a load. In this case, the first voltage-driven

switching element is preferably a power MOSFET, and the second voltage-driven switching element is preferably an IGBT.

[0014]

The semiconductor device preferably has a totem pole configuration in which one pair of the first and second voltage-driven switching elements connected in parallel, and another pair of the first and second voltage-driven switching elements connected in parallel, are connected in series.

[0015]

The semiconductor device preferably comprises a current detection section for detecting current flowing in the load; and a control section for switching a voltage to be output to the drive electrodes of the first and second voltage-driven switching elements, connected in parallel, between the first drive voltage and the second drive voltage based on a current value detected by the current detection section.

[0016]

The control section preferably outputs the first drive voltage having a level lower than that of the second drive voltage when the current value detected by the current detection section is smaller than a predetermined value.

[0017]

Thus-configured semiconductor device is successful in reducing the power loss ascribable to the switching element *per se* during a low-output operation, and also in adopting itself to the high-output operation, by allowing both of the IGBT having a small ON resistance and the power MOSFET having a large ON resistance to operate when a high output is required

within a short period of time such as at the start-up time, and by turning the IGBT intrinsically causative of junction-derived voltage drop off and allowing only the power MOSFET not causative of junction-derived voltage drop to operate during a low-power operation for a long duration of time, such as during the stationary operation.

[0018]

In the semiconductor device, a first threshold voltage of the first voltage-driven switching element and the second threshold voltage of the second voltage-driven switching element preferably differs by 2 V or more, and the predetermined value, which provides a judgment criterion for the switching by the control section between the first and second drive voltages, is preferably set to V_d/R_{on}, where V_d represents ON resistance of the first voltage-driven switching element, and V_d represents ON-time voltage drop of the second voltage-driven switching element.

[0019]

Because difference between the gate threshold voltages for gate driving of the power MOSFET and IGBT is set as large as 2 V or more in this configuration, it is made possible to certainly bring only the power MOSFET into ON state when the load current value is small. The difference between the threshold voltages for gate driving of as small as less than 2 V allows both of the power MOSFET and IGBT to turn on during the switching, and this undesirably delays the switching time because the gates of both elements must be charged, and increases the switching loss as compared with the case where

only the power MOSFET is driven. The above-described configuration, however, is successful in solving this problem.

[0020]

It is also made possible to optimize switching of operation of the power MOSFET and IGBT by setting a predetermined value of the detection current, which provides a judgment criterion for the switching of the gate drive voltages for the power MOSFET and IGBT, to a value obtained by dividing the voltage V_d which represents junction-derived voltage drop of the IGBT with the ON resistance R_{on} of the power MOSFET.

[0021]

It is preferable that the semiconductor device further comprises a first resistive element and a second resistive element; the first resistive element having a terminal connected to the drive electrode of the first voltage-driven switching element, the second resistive element having a terminal connected to the drive electrode of the second voltage-driven switching element, the first and second resistive elements having the other terminals connected to a common electrode; and that the control section outputs the first drive voltage or the second drive voltage to the common electrode.

[0022]

This configuration is successful in minimizing the switching loss during ON switching time and OFF switching time with respect to a margin for dV/dt malfunction tolerance, by connecting the gate resistors having optimum resistance values

respectively to the gate electrodes of the power MOSFET and IGBT.

[0023]

It is preferable that the semiconductor device further comprises a third resistive element having a terminal connected to the drive electrode of the first voltage-driven switching element and the other terminal connected to the drive electrode of the second voltage-driven switching element; a fourth resistive element having a terminal connected to the drive electrode of the first voltage-driven switching element; and a third switching element connected to the other terminal of the fourth resistive element, and turns the first voltage-driven switching element off based on a control signal from the control section while being mediated by the fourth resistive element; and that the control section outputs the first drive voltage or the second voltage to one terminal of the third resistive element.

[0024]

In this configuration, the IGBT is turned from the ON state into the OFF state by first turning the third switching element on using a control signal from the control section, short-circuiting the gate and source of the power MOSFET while being mediated by a resistor and the third switching element to thereby turn the power MOSFET off, and then lowering the gate voltage of the IGBT to thereby turn the IGBT off, and this is successful in preventing an over-current from flowing in the power MOSFET, and in reducing the switching loss during the off time.

[0025]

To accomplish the aforementioned object, a power control instrument of the present invention is characterized by using the above-described semiconductor device.

[0026]

Thus-configured power control instrument is successful in reducing the power loss ascribable to the switching element *per se* during a low-output operation, and also in adopting itself to the high-output operation, by allowing both of the IGBT having a small ON resistance and the power MOSFET having a large ON resistance to operate when a high output is required within a short period of time such as at the start-up time of an air conditioner, and by turning the IGBT intrinsically causative of junction-derived voltage drop off and allowing only the power MOSFET not causative of junction-derived voltage drop to operate during a low-power operation for a long duration of time, such as during the stationary operation. This makes it possible to reduce the power loss of the instrument as a whole over a long duration of use, and is successful in realizing more advanced energy saving.

[0027]

[Preferred Embodiment of the Invention]

The following paragraphs will describe preferred embodiments of the present invention referring to the attached drawings. It is to be noted that any elements having the same configurations and functions will be indicated by the same reference numerals.

[0028]

(First Embodiment)

Fig. 1 is a circuit diagram showing a configuration of a semiconductor device according to a first embodiment of the present invention. In Fig. 1, a semiconductor device 1 comprises a power MOSFET 2 (first voltage-driven switching element) and an IGBT 3 (second voltage-driven switching element) connected in parallel, a current detection resistor 4 (current detection section) for detecting electric current flowing in a load, and a control section 5 for switching a threshold voltage for gate driving to be output through a gate resistor 6 to a common gate terminal G of the power MOSFET 2 and the IGBT 3 depending on a magnitude of load current detected as voltage by the current detection resistor 4.

[0029]

The control section 5 comprises a driver 51 in charge of switching operation of the power MOSFET 2 and IGBT 3 depending on an externally supplied input signal V_{in}; a comparator 52 having a forward input terminal supplied with detected voltage V_s from the current detection resistor 4, having a reverse input terminal supplied with reference voltage V_{ref}, capable of outputting logic "1" level signal when the detected voltage V_s exceeds the reference voltage V_{ref}, and of outputting logic "0" level signal when the detected voltage V_s is lower than the reference voltage V_{ref}; and a switch 54 capable of outputting source voltage V_{cc} (second drive voltage) when an output signal from the comparator 52 has a logic "1" level, and of outputting a voltage V_{reg} (first drive voltage) lowered from the source voltage V_{cc} by a regulator 53 when an output signal from the

comparator 52 has a logic "0" level, in an alternately switched manner as a source voltage of a driver 5.

[0030]

When the gate drive voltage of the power MOSFET 2 and IGBT 3 is switched while assuming current flowing through the load as I_s, and resistivity of the current detection resistor 4 as R_s, the reference voltage V_{ref} of the comparator 52 is set to $V_{ref} = R_s \cdot I_s$.

[0031]

Assuming now that the threshold voltage for gate driving (first threshold voltage) of the power MOSFET 2 as 4.0 V, ON resistance R_{on} as 0.5 ? , the threshold voltage for gate driving (second threshold voltage) of the IGBT 3 as 7.5 V, the junction -derived voltage drop V_d as 0.6 V, the V_{cc} as 15 V and V_{reg} as 7.5 V, the load current I_s which induces switching of the gate drive voltages of the power MOSFET 2 and IGBT 3 is given as $I_s = V_d/R_{on}$ = 0.6 V/0.5 ? =1.2 A.

[0032]

The current flowing through the load of less than 1.2 A therefore results in operation of the power MOSFET only, because a relation of detected voltage $V_s<R_s \cdot I_s$ holds, and this allows the comparator 52 to output a signal of logic "0" level, allows the switch 53 to supply V_{reg} (= 7.5 V) as the source voltage to the driver 51, and allows the driver 51 to generate a gate drive voltage from V_{reg} (= 7.5 V) and to output it.

[0033]

On the other hand, the current flowing in the load equal to 1.2 V or larger results in operation of both of the power

MOSFET and IGBT, because a relation of detected voltage $V_s \geqq R_s \cdot I_s$ holds, and this allows the comparator 52 to output a signal of logic "1" level, allows the switch 53 to supply V_{cc} (= 15 V) as the source voltage to the driver 51, and allows the driver 51 to generate a gate drive voltage from V_{cc} (= 15 V) and to output it.

[0034]

In Fig. 2, V-I characteristic curves of the power MOSFET and IGBT used singularly are indicated by broken lines, and a V-I characteristic curve of the power MOSFET and IGBT connected in parallel is indicated by a solid line. As is obvious from Fig. 2, the voltage drop of the switching element is reduced in all current regions A, B and C, which indicates reduction in the loss.

[0035]

As is described in the above, the present embodiment is successful in reducing the power loss ascribable to the switching element *per se* during a low-output operation, and also in adopting itself to the high-output operation, by allowing both of the IGBT having a small ON resistance and the power MOSFET having a large ON resistance to operate when a high output is required within a short period of time such as at the start-up time of a high-power inductive load (in practice, setting of the ON resistance of the power MOSFET larger than that of the IGBT results in almost no current flowing in the power MOSFET), and by turning the IGBT intrinsically causative of junction-derived voltage drop off and allowing only the power MOSFET not causative of junction-

derived voltage drop to operate during a low-power operation for a long duration of time, such as during the stationary operation.

[0036]

The present embodiment is also successful in certainly bringing only the power MOSFET into ON state when the load current is small, by ensuring difference between the threshold voltages for gate driving of 2 V or more between the power MOSFET 2 and IGBT 3, where 3.5 V (= 7.5-4.0 V) was ensured in this embodiment. The difference between the threshold voltages for gate driving of as small as less than 2 V allows both of the power MOSFET and IGBT to turn on during the switching, and this undesirably delays the switching time because the gates of both elements must be charged, and increases the switching loss by approximately 20% as compared with the case where only the power MOSFET is driven. The above-described configuration, however, is successful in solve this problem.

[0037]

(Second Embodiment)

Fig. 3 is a circuit diagram showing a configuration of a semiconductor device according to a second embodiment of the present invention. In Fig. 3, the power MOSFET 2 and IGBT 3 connected in parallel have gate terminals G1 and G2 independent from each other, where one terminal of a resistor 31 (first resistive element) is connected to the gate terminal G1 of the power MOSFET 2, one terminal of a resistor 32 (second resistive element) is connected to the gate terminal G2 of the IGBT 3, and the other terminals of the resistors 31, 32 are commonly

connected so as to be supplied with the gate drive voltage from the control section 5.

[0038]

In the above-described configuration, setting of optimum resistivity values for the resistors 31, 32 adapted to the power MOSFET 2 and IGBT 3 is successful in minimizing the switching loss during the ON switching time and OFF switching time with respect to a margin for dV/dt malfunction tolerance.

[0039]

(Third Embodiment)

Fig. 4 is a circuit diagram showing a configuration of a semiconductor device according to a third embodiment of the present invention. In Fig. 4, a resistor 41 (third resistive element) which functions as a gate resistor of the power MOSFET 2 is connected between the gate terminal of the power MOSFET 2 and the gate drive voltage output terminal (V_G) of the control section 5, and the gate terminal of the IGBT 3 is directly connected to the gate drive voltage output terminal (V_G) of the control section 5. A resistor 42 (fourth resistive element) and a switching element 43 (third switching element) are connected between the gate terminal of the power MOSFET 2 and the low source voltage terminal V_n, and the gate terminal of the switching element 43 is connected to the control signal output terminal (V_c) of the control section 5.

[0040]

In thus-configured semiconductor device, IGBT 3 is turned from the ON state into the OFF state by first turning the third switching element 43 on using a control signal V_c from the

control section 5, short-circuiting the gate and source of the power MOSFET 2 while being mediated by a resistor 42 and the third switching element 43 to thereby turn the power MOSFET 2 off, and then lowering the gate drive voltage to be applied to the IGBT 3 to thereby turn the IGBT 3 off. This procedures allow the IGBT 3 to turn off earlier than the power MOSFET 2 because the IGBT 3 will have a larger threshold voltage for gate driving than that of the power MOSFET 2, prevent over-current from flowing into the power MOSFET 2, and make it possible to reduce the switching loss at the OFF time by approximately 15%.

[0041]

(Fourth Embodiment)

Fig. 5 is a circuit diagram showing a configuration of an inverter circuit for driving motor, such as for air conditioner, applied with a semiconductor device according to a fourth embodiment of the present invention.

[0042]

In Fig. 5, the inverter circuit comprises a switching section 5a for supplying adjusted power to the load, and a control section 5b for controlling operations of the switching section 5a. The switching section 5a has three totem-pole-connection structures, where the first one is a totem-pole-connection structure 51 which comprises a pair of a power MOSFET 5a-1 and an IGBT 5a-1′ connected in parallel and a pair of power MOSFET 5a-2 and an IGBT 5a-2′ connected in parallel; the second one is a totem-pole-connection structure 52 which comprises a pair of a power MOSFET 5a-3 and an IGBT 5a-3′

connected in parallel and a pair of power MOSFET 5a-4 and an IGBT 5a-4′ connected in parallel; and the third one is a totem-pole-connection structure 53 which comprises a pair of a power MOSFET 5a-5 and an IGBT 5a-5′ connected in parallel and a pair of power MOSFET 5a-6 and an IGBT 5a-6′ connected in parallel.

[0043]

The totem-pole-connection structures 51, 52 and 53 repetitively interrupt and allow current to be supplied to a three-phase motor 55 as the load in response to the gate voltages VG1 and VG2; VG3 and VG4; and VG5 and VG6 respectively output from three control integrated circuits 5b-1, 5b-2 and 5b-3 of the control section 5b.

[0044]

In this circuit, a high source voltage V_p and a low source voltage V_n are applied from an external power source to two power source terminals, where the high source voltage V_p is supplied to pairs on one side of the totem-pole-connection structures, which are the pair of power MOSFET 5a-1 and IGBT 5a-1′, the pair of power MOSFET 5a-3 and IGBT 5a-3′, and the pair of power MOSFET 5a-5 and IGBT 5a-5′, and the low source voltage V_n is supplied via a resistor 54 for detecting current flowing in the three-phase motor to pairs on the other side of the totem-pole connection structures, which are the pair of power MOSFET 5a-2 and IGBT 5a-2′, the pair of power MOSFET 5a-4 and IGBT 5a-4′, and the pair of power MOSFET 5a-6 and IGBT 5a-6′. The current flowing in the current detecting resistor 54 is detected as a voltage through sensing voltage input terminals (V_s) of the control integrated circuits 5b-1, 5b-2 and

5b-3, and the gate voltages VG1 to VG6 are controlled corresponding to the sensed voltage.

[0045]

Upon being applied with the gate voltages VG1 and VG2; VG3 and VG4; and VG5 and VG6; power to be supplied respectively from the output terminals of the totem-pole-connection structures 51, 52 and 53 to the W phase, V phase and U phase of the three-phase motor is controlled.

[0046]

Thus-configured present embodiment is successful in reducing the power loss ascribable to the switching element *per se* during a low-output operation, and also in adopting itself to the high-output operation, by allowing both of the IGBT having a small ON resistance and the power MOSFET having a large ON resistance to operate when a high output is required within a short period of time such as at the start-up time of air conditioners or the like (in practice, setting of the ON resistance of the power MOSFET larger than that of the IGBT results in almost no current flowing in the power MOSFET), and by turning the IGBT intrinsically causative of junction-derived voltage drop off and allowing only the power MOSFET not causative of junction-derived voltage drop to operate during a low-power operation for a long duration of time, such as during the stationary operation. This makes it possible to reduce the power loss of the instrument as a whole over a long duration of use, and is successful in realizing more advanced energy saving.

[0047]

Fig. 6 shows relations of time-dependent changes (a) in current waveforms I_A, I_B and I_C of the three phase motor 55 corresponded to current regions A, B and C shown in Fig. 2, with time-dependent changes (b), (c) and (d) in the gate drive voltages V_G of the totem-pole-connection structures corresponded to the current waveforms I_A, I_B and I_C, respectively.

[0048]

Such real-time detection of current values and optimization of the gate drive voltages were successful in reducing the loss in the switching elements by 15% under 1 Arms current, by 20% under 2 Arms current, and by 20% under 3 Arms current as compared with that in the conventional inverter circuit shown in Fig. 7.

[0049]

As has been described in the above, the present invention is successful in reducing the power loss ascribable to the switching element *per se* during a low-output operation, and also in adopting itself to the high-output operation, by allowing both of the IGBT having a small ON resistance and the power MOSFET having a large ON resistance to operate when a high output is required within a short period of time such as at the start-up time of a power inductive load, and by turning the IGBT intrinsically causative of junction-derived voltage drop off and allowing only the power MOSFET not causative of junction-derived voltage drop to operate during a low-power operation for a long duration of time, such as during the stationary operation.

[0050]

A power control instrument applied with the semiconductor device of the present invention makes it possible to reduce the power loss of the instrument as a whole over a long duration of use, and is successful in realizing more advanced energy saving.

[Brief Description of the Drawings]

[Fig. 1] A circuit diagram showing a configuration of a semiconductor device according to a first embodiment of the present invention.

[Fig. 2] A graph showing I-V characteristic curves of a power MOSFET and an IGBT used singularly, and a V-I characteristic curve of the power MOSFET and IGBT connected in parallel.

[Fig. 3] A circuit diagram showing a configuration of a semiconductor device according to a second embodiment of the present invention.

[Fig. 4] A circuit diagram showing a configuration of a semiconductor device according to a third embodiment of the present invention.

[Fig. 5] A circuit diagram showing a configuration of an inverter circuit for driving motor, applied with a semiconductor device according to the fourth embodiment of the present invention.

[Fig. 6] A drawing showing, in the fourth embodiment, relations of time-dependent changes (a) in current waveforms I_A, I_B and I_C of a three phase motor 55 corresponded to current regions A, B and C shown in Fig. 2, with time-dependent changes (b), (c) and (d) in the gate drive voltages V_G of the totem-

pole-connection structures corresponded to the current waveforms I_A, I_B and I_C, respectively.

[Fig. 7] A circuit diagram showing a conventional inverter circuit for driving motor.

[Description of the Reference Numerals]

1 semiconductor device

2, 5a-1 to 5a-6 power MOSFET (first voltage-driven switching element)

3, 5a-1′ to 5a-6′ IGBT (second voltage-driven switching element)

4, 54 current detection resistor (current detection section)

5, 5b control section

5a switching section

5b-1 to 5b-3 control integrated circuit

31 resistor (first resistive element)

32 resistor (second resistive element)

41 resistor (third resistive element)

42 resistor (fourth resistive element)

43 switching element (third switching element)

51, 52, 53 totem-pole-connection structure